LOG-POLAR PHASE-ONLY CORRELATION APPLIED TO BEETLES SYSTEMS OF GALLERIES

CORELAȚIA ÎN FAZĂ CU TRANSFORMATĂ LOG-POLARĂ PENTRU CLASIFICAREA SISTEMELOR DE GALERII LARVARE

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Abstract: *Pattern recognition in the present study is based on the image capture and the correlations using log-polar transform and phase-only correlation. The beetles systems galleries' architecture is captured on digital images, further cleaned for image enhancement and finally analyzed using comparators based on natural models. The correlators extract those image segments which remain invariant despite the variations induced by biotic and abiotic factors to the architecture of galleries.*

Rezumat: *În prezentul studiu recunoaşterea de forme se bazează pe digitizarea imaginilor şi a corelațiilor în fază folosind şi transformarea log-polară. Sistemul de galerii larvare este capturat în imagini digitale, curățat de eventualele artefacte pentru a obține o imagine clară şi este analizată în corelatoare având la bază informație dată de modele naturale. Corelatoarele extrag acele segmente care conțin caracteristici invariante chiar dacă aceste arhitecturi ale galeriilor prezintă variabilitate indusă de factori biotici sau abiotici.*

Key words**:** *pattern recognition, beetles systems of galleries, phase-only correlation, log-polar transform*
Cuvinte cheie**:** *recunoaştere de forme, sistem de galerii larvare, corelație în fază, transformare log-polară*

INTRODUCTION

Pattern recognition is an area of increasing interest due to applications in environmental sciences. The correct identification of an organism is of major importance in ecological studies and there is an enormous body of knowledge dedicated to classification and recognition of species. Two main directions define the effort to identify organisms in present days: molecular methods and advances in pattern recognition based on morphological features of species.

Bark and wood inhabiting insects are key species for forest ecosystems: they are involved in matter recycling process and have a major impact on structure and functioning of forest ecosystems during population explosions produced recurrently, mainly in managed forests.

The identification of bark inhabiting beetles (fam. *Scolytidae*) is based on morphological features of adult beetles (imago) and on the architecture of galleries systems carved by adults as well as larvae under the bark.

The galleries architecture is species –specific and represents a special category of external morphological features assigned to bark insects. Every species display a particular architecture of this system which can be approached for pattern recognition. We selected two different patterns of galleries characteristic to two species of bark beetles: *Ips typographus* and *Hylesinus fraxini,* with the goal of verifying the discrimination power of the pattern recognition method.

MATERIAL AND METHODS

A. Phase-only cross-correlation

Matching process is used for object registration that means that one object is “compared” with several objects. Comparison criteria concludes if the compared objects or not similar with other objects. The comparison process works basically with two objects. In our case the comparison method is the cross-correlation and the objects are the beetles systems of galleries digital images.

In a single cross-correlation process the two objects are denoted as reference and non-reference. That means from cross-correlation process we obtain the information of the reference is similar or not with the non-reference object.

The classical cross-correlation considers two (N×M) images, $ref(x,y)$ as reference image and $nref(x,y)$ as non-reference image. The 2D discrete Fourier transforms of these images, denoted as $Ref(u,v)$ and $NRef(u,v)$, are given by (L. H. CHIEN et al. 2004, T. SHIBAHARA et al. 2005, K. MIYAZAWA et al.. 2005, K. ITO et al. 2005, K. TAKITA et al. 2003, K. ITO et al. 2004, K. ITO et al. 2006, TEUSDEA, A.C. & GABOR, G. 2008, TEUȘDEA ALIN C., GABOR G. 2008)

$$Ref(u,v) = REF(u,v) \cdot e^{i \cdot \varphi_{ref}(u,v)}, \quad (1)$$

$$NRef(u,v) = NREF(u,v) \cdot e^{i \cdot \varphi_{nref}(u,v)}, \quad (2)$$

$$REF(u,v) = \left[Ref(u,v) \cdot \overline{Ref(u,v)}\right]^{0.5} \quad (3)$$

$$NREF(u,v) = \left[NRef(u,v) \cdot \overline{NRef(u,v)}\right]^{0.5} \quad (4)$$

where $REF(u,v)$ and $NREF(u,v)$ are the amplitude part, $\varphi_{ref}(u,v)$ and $\varphi_{nref}(u,v)$, are the phase part of the 2D discrete Fourier transforms.

The classical cross-spectrum $CS_{RN}(u,v)$, between $REF(u,v)$ and $NREF(u,v)$, is given by (L. H. CHIEN et al. 2004, T. SHIBAHARA et al. 2005, K. MIYAZAWA et al.. 2005, K. ITO et al. 2005, K. TAKITA et al. 2003, K. ITO et al. 2004, K. ITO et al. 2006, TEUSDEA, A.C. & GABOR, G. 2008, TEUȘDEA ALIN C., GABOR G. 2008)

$$CS_{RN}(u,v) = Ref(u,v) \cdot \overline{NRef(u,v)} \quad (5)$$

$$CS(u,v) = REF(u,v) \cdot e^{i \cdot \varphi_{ref}(u,v)} \cdot NREF(u,v) \cdot e^{-i \cdot \varphi_{nref}(u,v)} = REF(u,v) \cdot NREF(u,v) \cdot e^{i \cdot \Delta\varphi_{rn}(u,v)} \quad (6)$$

where $\Delta\varphi_{rn}(u,v) = \varphi_{ref}(u,v) - \varphi_{nref}(u,v)$ is the phase difference .

Classical correlation function, $ClC_{RN}(u,v)$, is the 2D inverse discrete Fourier transform of classical cross-spectrum, $CS_{RN}(u,v)$, given by

$$ClC(x,y) = \frac{1}{N \cdot M} \sum_{u=1}^{N} \sum_{v=1}^{M} \left[CS(u,v) \cdot e^{-\frac{2\pi i}{N}ux} e^{-\frac{2\pi i}{M}vy} \right] = \frac{1}{N \cdot M} \sum_{u=1}^{N} \sum_{v=1}^{M} \left[REF(u,v) \cdot NREF(u,v) \cdot e^{i \cdot \Delta\varphi_{rn}(u,v)} \cdot e^{-\frac{2\pi i}{N}ux} e^{-\frac{2\pi i}{M}vy} \right] \quad (7)$$

This 2D function presents a highly wide cross-correlation peak when $ref(x,y) = nref(x,y)$. When $ref(x,y) \neq nref(x,y)$ then the cross-correlation peak strongly decreases.

The phase only cross-spectrum (L. H. CHIEN et al. 2004, K. ITO et al. 2005, K. TAKITA et al. 2003, K. ITO et al. 2004, K. ITO et al. 2006, TEUSDEA, A.C. & GABOR, G. 2008, TEUȘDEA ALIN C., GABOR G. 2008) is defined by

$$PO\_CS(u,v) = \frac{ClC(u,v)}{|ClC(u,v)|} = \frac{REF(u,v) \cdot NREF(u,v) \cdot e^{i \cdot \Delta\varphi_{rn}(u,v)}}{\left|REF(u,v) \cdot NREF(u,v) \cdot e^{i \cdot \Delta\varphi_{rn}(u,v)}\right|} = e^{i \cdot \Delta\varphi_{rn}(u,v)} \quad (8)$$

and thus the phase only cross-correlation is given by

$$POC(x,y) = \frac{1}{N \cdot M} \sum_{u=1}^{N} \sum_{v=1}^{M} \left[PO\_CS(u,v) \cdot e^{-\frac{2\pi i}{N} ux} e^{-\frac{2\pi i}{M} vy} \right] = \frac{1}{N \cdot M} \sum_{u=1}^{N} \sum_{v=1}^{M} \left[e^{i \cdot \Delta\varphi_{rn}(u,v)} \cdot e^{-\frac{2\pi i}{N} ux} e^{-\frac{2\pi i}{M} vy} \right] \quad (9)$$

If $ref(x,y) = nref(x,y)$ then $\Delta\varphi_{rn}(u,v) \equiv 0$ and the phase only correlation is give by

$$POC(x,y) = \frac{1}{N \cdot M} \sum_{u=1}^{N} \sum_{v=1}^{M} \left[1 \cdot e^{-\frac{2\pi i}{N} ux} e^{-\frac{2\pi i}{M} vy} \right] = \delta(x,y) \quad (10)$$

This means that if the two images are identical then the phase-only correlation gives a highly sharp peak so the matching accuracy is higher than in the classical method.

B. Log-Polar transform

Usually a rotation invariant approach for these correlators is to apply somehow the log-polar transform (KURITA T. et al. 1997). This transform is performed in two steps.

In the first step the rectangular coordinates (u, v) of the cross-spectrum are transformed in polar coordinates (r, θ).

In the second step the r coordinate is transformed via logarithmic function $\rho(r) = ln(r)$. In this way the pattern recognition process can accommodate eventually rotations of the beetles systems of galleries digital images from the same species.

RESULTS AND DISCUSSIONS

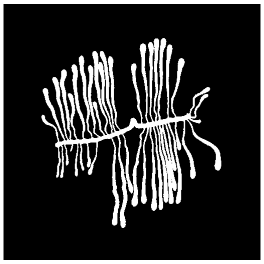
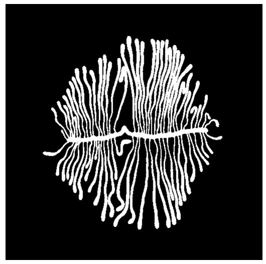
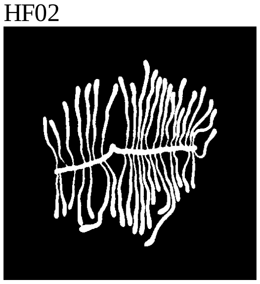
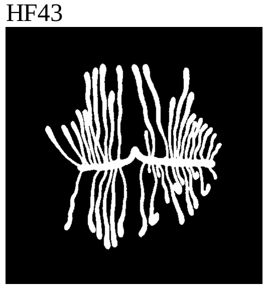
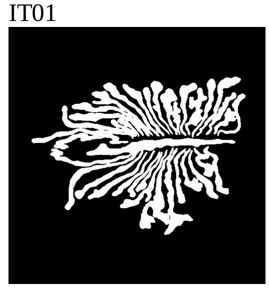
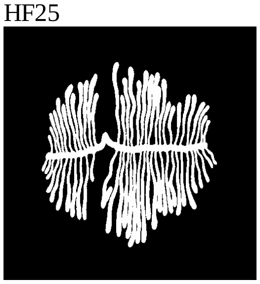
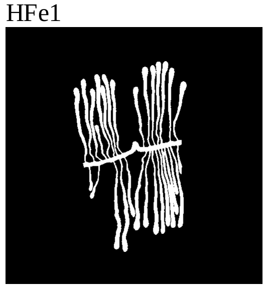
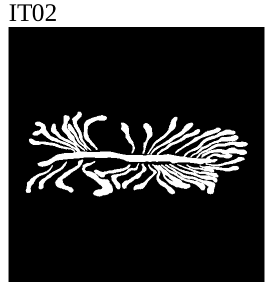
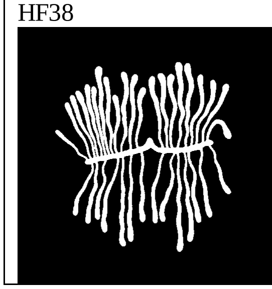
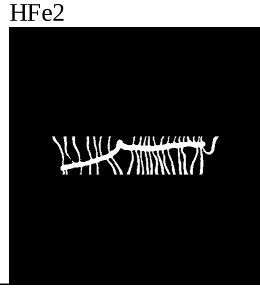
The beetles systems of galleries digital images database used in this paper has 8 images (with index HF01, HF02, HF25, HF38, HF42, HF43, HFe1, HFe2) for and *Hylesinus fraxini* and 2 images (IT01 and IT02) for *Ips typographus* (table 1). Images with index HFe1 and HFe2 are cropped (vertically and horizontally) from image with index HF01.

Table 2 presents the pattern recognition results from log-polar phase-only correlations of images from the used database as the CPI (cross-correlation peak intensity) values. In this table the API (autocorrelation peak intensity) values are marked with italics.

Table 3 contains the minimum value of the correlation CPI for the genuine class of *Hylesinus fraxini* images (minAPI) and the maximum value of the correlation CPI for the impostor class of *Ips typographus*. These individual values were the threshold for the pattern recognition process in witch every *Hylesinus fraxini* image was individual considered as a genuine class (TEUSDEA, A.C. & GABOR, G. 2008, TEUȘDEA ALIN C., GABOR G. 2008). The results of these individual pattern recognition processes are presented in figure 1.

Table 1

Beetles systems of galleries digital images database

HF01 	HF42 	
HF02 	HF43 	IT01 
HF25 	HFe1 	IT02 
HF38 	HFe2 	

From the results presented in figure 1, it can be seen that the HF42 index image is the perfect reference for the *Hylesinus fraxini* specie as the GAR has 1.00 values and the FAR is 0.00. The GAR means the genuine acceptance rate and represents the number of genuine positive verifications against the total number of genuine verification attempts – for good pattern recognition systems the GAR value should be next to 1.00. The FAR means the false acceptance rate and represent the number of impostor accepted as genuine against the total number of impostor verification attempts – for good pattern recognition systems the FAR value should be next to 0.00. The FRR=1-GAR and means the false rejection rate and represents the false rejected genuine as impostors.

Table 2

Pattern recognition results from log-polar phase-only correlations of images from table 1

CPI	HF01	HF02	HF25	HF38	HF42	HF43	HFe1	HFe2
HF01	*6.87E+10*	3.51E+08	4.21E+08	4.85E+08	6.77E+08	1.27E+08	3.30E+10	2.60E+08
HF02	3.51E+08	*6.87E+10*	5.91E+08	2.80E+08	3.43E+08	2.22E+08	3.49E+08	6.09E+08
HF25	4.21E+08	5.91E+08	*6.87E+10*	3.43E+08	3.09E+08	1.29E+08	2.62E+08	2.42E+08
HF38	4.85E+08	2.80E+08	3.43E+08	*6.87E+10*	4.67E+08	2.73E+08	2.40E+08	1.81E+08
HF42	6.77E+08	3.43E+08	3.09E+08	4.67E+08	*6.87E+10*	2.44E+08	5.75E+08	2.07E+08
HF43	1.27E+08	2.22E+08	1.29E+08	2.73E+08	2.44E+08	*6.87E+10*	1.15E+08	2.04E+08
HFe1	3.30E+10	3.49E+08	2.62E+08	2.40E+08	5.75E+08	1.15E+08	*6.87E+10*	1.32E+08
HFe2	2.60E+08	6.09E+08	2.42E+08	1.81E+08	2.07E+08	2.04E+08	1.32E+08	*6.87E+10*
IT01	3.35E+08	2.71E+08	1.59E+08	2.23E+08	1.17E+08	1.06E+08	2.94E+08	1.04E+08
IT02	1.31E+08	1.32E+08	1.64E+08	1.00E+08	9.89E+07	1.65E+08	1.32E+08	1.92E+08

Table 3

Correlation peak intensity thresholds for *Hylesinus fraxini* images

minAPI	1.27E+08	2.21E+08	1.29E+08	1.81E+08	2.07E+08	1.14E+08	1.14E+08	1.31E+08
maxCPI	3.35E+08	2.71E+08	1.64E+08	2.23E+08	1.16E+08	1.65E+08	2.94E+08	1.91E+08

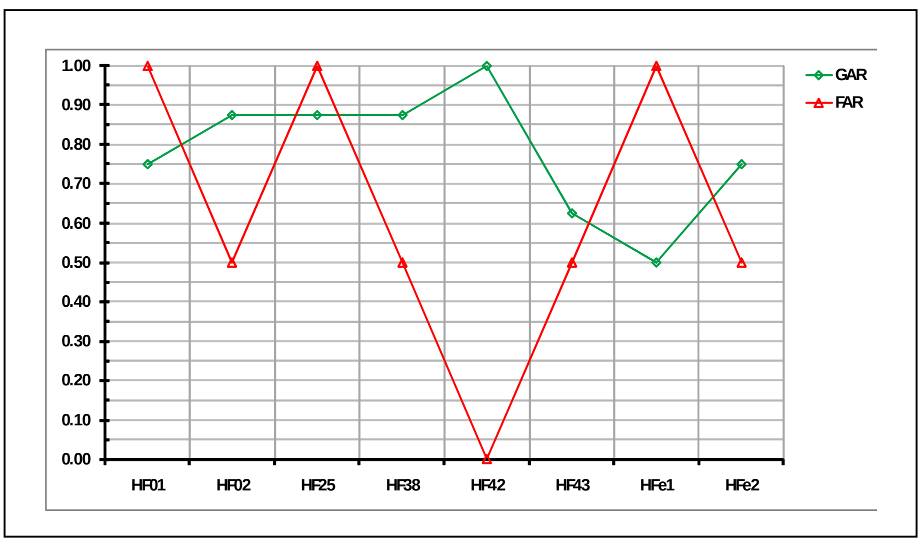


Figure 1. Genuine acceptance rate (GAR) and false acceptance rate (FAR) for the correlations of *Hylesinus fraxini* images calculated with correlation peak intensity thresholds from table 3

From figure 1 it can be seen that despite the high values of GAR for individual pattern recognitions with HF01, HF25 and HFe1 images the FAR values are also high. This means that these images aren't representative for the *Hylesinus fraxini* specie.

The overall beetles systems of galleries digital images database pattern recognition results are presented in figure 2 as the FAR and FRR diagrams over 16 correlation intensity peak values as threshold. The EER is the equal error rate that represents the FRR and FAR values witch are the same value. The smaller EER value the better. From the figure 2 one can see that the EER value for the overall pattern recognition experiment is 0.15625 for witch the GAR coefficient is 0.84375 or 84.375%.

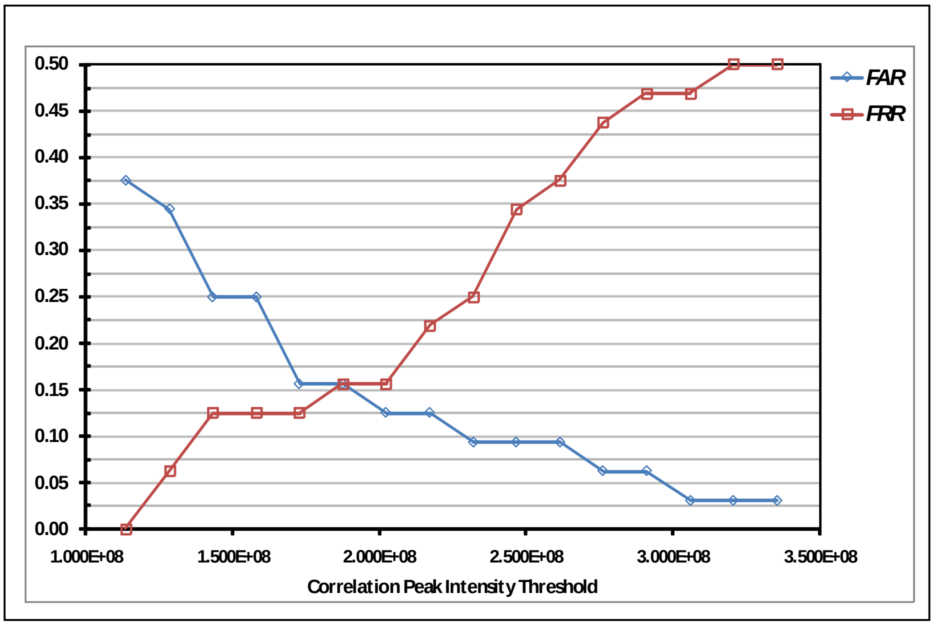


Figure 2. False acceptance rate (FAR) and false rejection rate (FFR) diagram for all the correlations of images from the used database

CONCLUSIONS

This paper presents the pattern recognition process applied over beetles systems of galleries digital images database. The correlation method is log-polar phase-only correlation used to be robust to some small rotations of the galleries systems in the digital captured images.

The GAR (Genuine Acceptance Rate – as a quantitative pattern recognition efficiency) obtained for the galleries was around 84% taking into account the fact that there was a relatively high variability among galleries of the same specie.

This result is significant and positive under the assumption that GAR coefficient reported for human fingerprints from the same individual, same hand and same fingers was 92.76%, accepted as positive performance.

The EER value that generates this GAR value is 15.6% that denotes a good pattern recognition method for the used database. These pattern recognition results entitle this method to determine the intensity attack of beetles with accuracy and as a consequence to apply the right quantity of chemical treatment in order to provide an environmental protection.

Future work should consider a bigger database to ensure higher statistical significance for the application.

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